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Vaudrey et al.

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(54) **ACTIVE NOISE REDUCTION FOR AUDIOMETRY**

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(51) **Int. Cl.**[7] **H04R 29/00**
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(58) **Field of Search** 381/60, 71.6, 71.7, 381/71.11, 72, 74; 73/585; 600/559

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,647,969 A		3/1972	Arguimbau et al.	
3,648,196 A		3/1972	Gay	
3,793,484 A		2/1974	Feezor	
3,793,485 A		2/1974	Feezor	
3,809,811 A		5/1974	Delisle et al.	
4,224,468 A		9/1980	Calder	
4,768,165 A		8/1988	Hohn	
5,197,332 A		3/1993	Shennib	
5,481,615 A	*	1/1996	Eatwell et al.	381/71.6
5,721,783 A	*	2/1998	Anderson	381/316
5,815,582 A	*	9/1998	Claybaugh et al.	381/71.6
5,825,894 A	*	10/1998	Shennib	381/60
5,852,667 A	*	12/1998	Pan et al.	381/71.6
6,058,194 A	*	5/2000	Gulli et al.	381/72
6,160,893 A	*	12/2000	Sauders et al.	381/71.6

OTHER PUBLICATIONS

"Audiometric Ear Canal Probe with Active Ambient Noise Control", by Rafaely Boaz, *IEEE Transactions on Speech and Audio Processing*, vol. 4, No. 3, May 1996.

* cited by examiner

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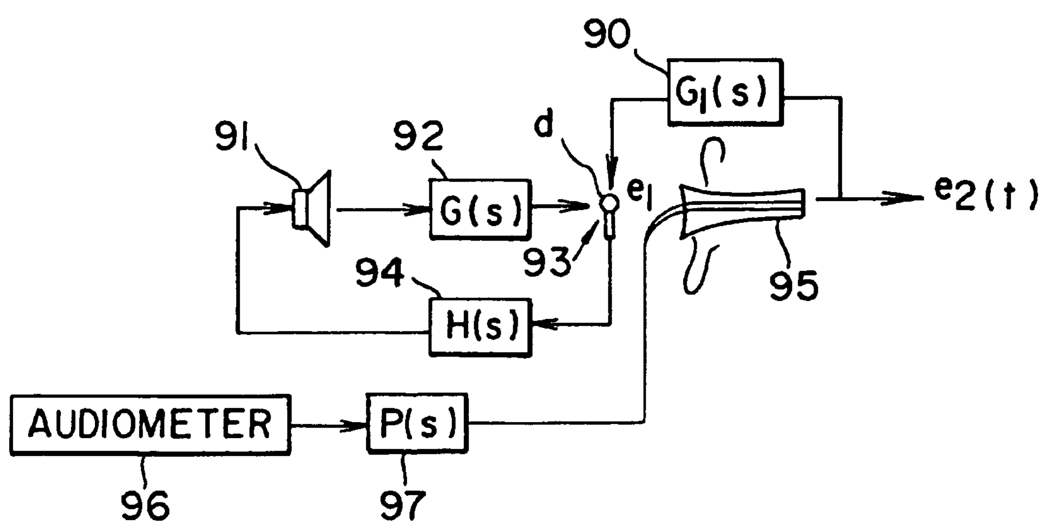
(57) **ABSTRACT**

The technology of active noise reduction (ANR) is incorporated into audiometry testing in a variety of formats. Analog feedback, digital feedback, adaptive feedforward, and adaptive feedback noise control schemes are presented for use in audiometry to reduce the ambient noise heard by the test subject, allowing subject testing in higher ambient noise fields. Audiometer test signals are appropriately compensated so the test results are accurate and comply with existing calibration standards for audiometers. Existing audiometry headphone technologies are modified so that ANR can be accomplished while satisfying existing standards for audiometric testing. Embodiments are also defined for alternate headphone arrangements that may not conform to current (1997) audiometric testing standards but provide sufficient performance advantages to warrant new standards for audiometry testing in the future.

8 Claims, 5 Drawing Sheets



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TITLE: Active noise reduction for audiometry

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Application Filing Date - AD (1):
19980220

Detailed Description Text - DETX (2):
A large number of applications of active noise control (ANC) have been confined to laboratory experiments performed under carefully controlled conditions. However, in the past decade, ANC has found a specific market in hearing protection devices. Headsets designed to protect the wearer from harmful sound pressure levels now incorporate both passive and active measures. Passive control (typically in the form of a circumaural cushion) is most effective at protecting the wearer from high frequency disturbances whereas active control is most effective for frequencies below 1 kHz. By placing the active noise control system inside the headset and **close to the user's ear,** manufacturers of these devices take advantage of a local zone of silence created around the error microphone, as well as minimal power requirements for the near-field architecture of ANR headsets.

Detailed Description Text - DETX (10):
The microphone should be placed as close as possible to the subject's eardrum and as close as possible to the speaker. In order to satisfy both conditions, the speaker needs to be located very **close to the subject's ear**. FIG. 3 illustrates an example of this concept with a speaker (actuator) (20), microphone (sensor) (21) and subject (22). Distance d.sub.1 is small enough to be in the acoustic near field of the speaker (less than the radius of reverberation) while d.sub.2 is small enough to be less than the radius of the area of silence so that the highest desired frequency of noise reduction is perceivable by the test subject. Therefore, each of these distances is a function of the speaker size and ear canal depth, respectively.

Detailed Description Text - DETX (15):
Although the constraints of the standards for test stimulus delivery have been compatible with the previously described innovations in active noise control for audiometry, it is a further embodiment of this invention to provide a generic audiometer which incorporates active noise control without necessarily meeting applicable standards. A headphone system that has superior passive performance and incorporates active noise control, can be designed to deliver a known SPL to a subject's eardrum. The cross section of one such device is shown in FIG. 7. A larger volume (40) is provided to easily house the ANC sensor (38) and to bring it equally **close to the subject's ear** and speaker. A circum-aural passive seal (39) is provided which more effectively attenuates high frequencies than the conventional supraural cushion. A design such as this will improve both active and passive performance but will likely not meet applicable standards due to the circum-aural contact and excess volume

in front of the speaker. However, a new calibration procedure is proposed for this system by first determining the average subject's eardrum location and enclosed volume. Then each test tone can be calibrated with an SPL meter located at the virtual average eardrum in a fixture that approximates the average human skull, pinna, ear canal combination. This is precisely the same Procedure used to calibrate the current standard; it is simply an estimate of the average human's auditory frequency response characteristics.

Detailed Description Text - DETX (33):

Feedforward control offers a distinct advantage over feedback for ANR audiometry in that the test stimulus can be delivered to the subject unaffected by the control action, without any additional modifications. As discussed during the plant design section above, the error sensor (microphone) should be located **close to the subject's ear** to maximize noise control performance. Given this, whether one or two actuators are used in feedforward control, the error sensor will detect at least some of the test stimulus as it is delivered to the subject. However, as long as the reference sensor does not detect or contain signal content from the test stimulus (i.e. coherence is low), the feedforward controller will have no effect on the test stimulus. For this reason, the combined feedback and feedforward control option will only require modification as a result of the feedback control force, and not the feedforward. In the case of two actuators and combined feedback and feedforward control, the equation above will apply since the feedforward control action will have no affect on the test stimulus.

Claims Text - CLTX (18):

8. The system as in claim 6 wherein said pre-filter means for calibrating the audiometric test stimulous is the causal **inverse of the said attenuation** control means thereby delivering the audiometric test stimulous to the said test subject, unaffected by said control means.